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Historic paths and future expectations: the macroeconomic impacts of the offshore wind technologies in the UK.

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Abstract

Offshore wind power (OSW) plays a key role within the UK strategy for a transition towards a low-carbon economy, offering vast potential for establishing a high-tech manufacturing industry in the country. However, previous experiences in the onshore sector (OWP) suggest the UK might fail in fully capture these macroeconomic benefits. In this work, we investigate the history of UK renewable policies, comparing its national strategy to those of other major OSW export countries. Further, through the use of a numerical general equilibrium model, we quantify the macroeconomic impacts under three scenarios: a baseline, which relies on previous estimates and foresee limited local content; a 'contamination' scenario, where the UK content reaches the same levels of OWP; and a 'non-myopic' scenario, where investors expect feeble support to vary or disappear as support policies as uncertain as in the past decades. Through the combination of historic comparative policy analysis, we identify the UK as a FDI-oriented country. Our modelling experiments suggest that increasing the local supply of capital goods related to OSP to OWP-level could generate larger income and employment effects in the UK economy. Furthermore, we find that under forward-looking investors the economic benefits are significantly lower than the case of myopic agents. Our results show an inherent conflict with stated purposes of UK policy for OWP. Jobs creation could be over-estimated, while continuous uncertainty hampers the participation of investors.

1. Introduction

1.1. *Role of onshore/offshore wind (OSW) within UK: low-carbon, manufacturing and energy security*

Offshore wind energy (OSW) is the amongst the most popular and fastest growing renewable energy technologies (RETs) in Europe (Kern et al., 2014; Dawley et al., 2015). In the UK, the country with the largest OSW installed capacity worldwide (IRENA, 2013d), the adoption of this technology is driven by three main objectives: lowering the overall carbon emissions of the country, increasing energy security through the exploitation of a domestic resource, and providing new manufacturing jobs (Dawley et al. 2015; HM Government 2013; McNeil et al. 2013; The Scottish Government 2010; The Scottish Government 2011). Although the first two objectives can be achieved simply increasing the installed capacity and the electricity output produced using OSW and other renewables, the third objective depends on 'where' the supply chain of OSW is located. Understanding the economic impact of OSW is one of the major focuses in the recent stream of literature in the UK and its sub-regions, particularly Scotland, where most of the OSW potential is located.

For example, CEBR (2012) estimated the employment impacts and contribution to GDP that the OSW would provide to the UK economy under different scenarios formulated following the total installed capacity by 2020 and 2030. The authors used an input-output approach based on previously calculated, sector-specific multipliers, and previously developed local content estimates (CEBR 2012). The report found that OSW could increase the UK's GDP (0.3-0.6% by 2030), creating about 40,000 full time equivalent (FTEs) jobs by 2020, and 60,000 by 2030. More significantly, the report highlights the how OSW would have the potential to become a major export-oriented industry, possibly re-balancing the trade gap through increased exports of electricity (CEBR 2012). The reliance on electricity exports features prominently in CEBR's assumptions, making it possible to achieve positive net trade impacts their scenarios, whit only two, long-term (2030) estimates finding larger goods/services exports greater than imports in the OSW sector. This assumption, although grounded in the vast OSW resource endowment of the UK, carries a few sources of risk: it relies on the expectation that an electricity infrastructure will be built, and that other EU countries do not possess and/or will not tap their own OSW or other renewable resources within the same time frame.

The depiction of OSW-generated electricity as an export commodity for the UK might be over-optimistic, at least within the assumed time-frame.

In another work, Lecca et al (2016) used a multi-sectoral energy-economy-environmental model to evaluate the macroeconomic and energy impacts of reduction in OSW levelized cost of energy, as foreseen by the UK Department of Energy and Climate Change (DECC). Their work found that if agents are myopic then substitution among generation technologies is not considered. More importantly, the authors found that, if the installation objectives are to be reached (22 GW by 2030), the OSW would increase GDP between 0.03-0.15% from the base-year values, and employment between 0.03 and 0.13%, assuming UK content slightly increases by 2030.

Similar magnitudes of contribution to employment and GDP were found by other studies reviewed by McNeil et al (2013). This study has highlighted the volatility of the impacts depending not only on the total installed capacity, but mainly on the share of 'domestic' content (i.e. UK) assumed in the capital and operational expenses (CAPEX and OPEX). In addition, the local content influences the overall economic impact of the OSW sector through another element: the value of exports in goods and services to other EU and non-EU countries, which serves as a driver for sustaining the new domestic production beyond the capacity of internal demand, and has been sought after by the Scottish Government for rebuilding advanced manufacturing capacity (Scottish Government, 2010).

Despite different overall results, the literature on OSW economic impacts[1] recognizes the importance of correctly quantifying the local content of goods and services for understanding the larger economic impacts of OSW (e.g. Roberts et al, 2014; Gillmartin and Allan, 2015). The location of the supply chain, in turn, is highly driven by the industrial policies, which play a fundamental role as firms' determinants, both spatially and organizationally (Lund, 2009; Lewis and Wiser, 2007; Kern et al, 2014; Dawley et al, 2015). The policies driving the rise of a new industrial sector are not created in a vacuum, but, rather, they arise from path-dependant processes occurring through time and across regions (Boschma and Frenken, 2006; Boschma and Frenken, 2011; Martin, 2010; Dawley et al, 2014). Because of this path-dependency, modelling the future economic impacts of the OSW sector

[1] For a comprehensive review of the literature see McNeil et al. (2013).

can be better understood looking at the past and current support policies, domestically and in other (potentially competitor-like) countries, as well as at similar, more mature sectors (Wang, 2010), which often include the same firms. In the case of OSW, this sector is onshore wind power (OWP) (Söderholm and Pettersson, 2011; Nemet, 2012; Weiss et al. 2013; Gernaat et al., 2014).

In this work, we investigate the policies which have shaped the current OSW sector in the UK, and parallel policies implemented in Germany, Denmark and Spain, the largest OSW export countries in Europe (IRENA, 2013a; IRENA, 2013b; IRENA, 2013c). This historic policy analysis includes both OSW policies and policies that have influenced a parallel sector, on-shore wind power. Building upon this historic policy analysis, we model and evaluate the economic impact of expanding OSW capacity in the future utilizing the UKENVI model, a general equilibrium modelling framework for the UK (Allan et al., 2007; Lecca et al., 2014; Lecca et al., 2016), - focusing primarily*) on* the overall impacts of an increased UK content, up to the levels reached in the OWP sector, which represents the 'premium' for implementing one or a combination of the policies other European countries have implemented; and *b) on* the effects of allowing economic agents, investors in particular, to expect incentives to end in the future (non-myopic), thus showing the difference between continuous support and uncertainty related to support policies.

The reminder of the paper is organized as follows. In Section 2, we investigate the OSW-related policies in the UK, and compare them to other major wind power countries for understanding the historic path that has led the UK to be a large adopter and a small manufacturer of OSW. In Section 3, the methods and the simulation strategy adopted to evaluate the economic effects of OSW are described while the results of alternative scenarios are discussed in Section 4. Finally, conclusions and policy implications are drawn in Section 5.

2. The broken path of wind: a review of the 'arrested development' of British technology

The history of UK wind power dates back to the 1700s, when circa 2% of the national power requirements where met through the use of wind-mills (Jones and Boumane, 2011). In 1891 it was a Scotsman, James Blyth, who patented the first turbine for electricity generation (Brice, 1992). In

1895, the first start-up venture for wind machines started to operate in London, the Rollason Wind Motor Company (Jones and Bouamane 2011). Despite this tradition, however, steam power and large coal mines halted the development of a system of research and development in wind energy (Jones and Bouamane, 2011). After the 1973 oil shock, when green energy sources started to gather attention and other countries invested in wind, Britain had very few engineers trained in wind power, and it was concluded that it was a medieval technology, not fit for the contemporary world (Grubb 1990a).

The lost decade of the 1970s caused the UK to stay behind in production, and to become a net importer of onshore wind technology (Bossany, 1983). In 1981, the first large-scale wind-power generator installed in the Orkney Isles (55kW) came from Denmark; another 200kW machine installed at Carmarthen Bay came from the US (Bossany, 1983). When in 1982 Howden Ltd, the UK leader in the construction of wind turbines, tried to enter the California market, serious reliability issues caused it to withdraw only two years later (Jones and Boumane, 2011), and to close its wind turbine manufacturing altogether in 1989 (Townsley, 1989). Furthermore, nothing impelled the British government to carry out a serious investment programme in wind energy: by 1985 the counter-oil shock had collapsed oil prices, and wind power was not supported by environmentalist movements, which on the contrary attacked the aesthetic impact of wind towers (McKie, 1985).

In 1989, the Electricity Act that privatised electricity generation seemed to bring about a new era for the UK wind power industry. The law included the adoption of a Non-Fossil Fuel Obligation (NFFO) that required the new private Regional Electricity Companies (RECs) to make power-purchase contracts with non-fossil fuel generated electricity, at levels set by the Secretary of State for Energy. The additional costs of these contracts would be covered by the State through a new tax on fossil fuels generation (Elliott 1992). The NFFO was designed to promote nuclear power, but it proved extremely successful with renewables, and especially with wind energy: in the first round of NFFOs the goal for renewables was to reach a production of 50MW by 1992 (Elliott 1992); instead, wind farms alone reached 600MW by 1990 (Grubb 1990a). This extraordinary performance promoted a new wave of optimism around wind; several analyses predicted that wind power could have generated up to 20% UK electricity needs by 2000, and up to 30% by 2030, especially with the development of offshore wind (Clarke 1991). However, the NFFOs were not designed for renewables, and the government failed to take action to promote local content, R&D departments, or even increase the NFFO quota for wind energy, which was smaller than its potential (Brice 1992). Furthermore, in 1990 the European Commission ruled against the NFFOs system according to the fair competition rule, as it was to all effect a covert subsidy to nuclear power. The UK negotiated an 8-year extension of the scheme, but uncertainty over prices at the end of the extension period alienated investments in renewables (Clarke, 1991). Wind, in particular, with low running costs but particularly high up-front investments, was severely hit (Elliott 1992). Without other incentives from the government, at the turn of the millennium the UK was behind the rest of Europe in the production of wind power, as well as other renewables

In 2002 NFFOs were replaced by the Renewable Obligations Certificates (ROCs), which are partly still in place. ROCs require electricity suppliers to source an increasing proportion of electricity from renewable sources (25-nat-ren-energy-action-plan). This scheme has helped wind power in Britain considerably: BWEA members are its largest beneficiaries, and in the period 2000-2014 UK wind power capacity has grown from 425MW to 12,809MW, filling the gap with Denmark, which grew from 2,341MW to 4,778MW

The 2013 Energy Act and the Electricity Market Reform promoted long-term investments through guaranteed price support into the 2030s (HM Government 2013), thanks to a new tool available to the renewable energy industry: Contracts for Difference (CFD) between low carbon energy generators and the government, which allows clean electricity to be sold at a competitive price in spite of initial investments. Thanks to these measures, between 2013 and 2014 installed capacity went up by 14.3% (BP, 2016), and reached 5,060 MW in 2015, the largest OSW capacity in Europe (EWEA, 2016a).

In spite of these progresses in the diffusion of OWP, which can be seen in line with the first 2 objectives of the UK government, local content has not grown accordingly (BVGA, 2014; Royal Academy of Engineering, 2014). The UK lacks a major international player in turbines manufactures, and it is mostly reliant on foreign investments. Even though the Electricity Act tackled the problem of technology gap, with a £20-million investment in the Regional Growth Fund and the creation of two new government bodies energy (HM Government, 2013), only 12 out of 50 offshore wind energy projects see the involvement of British-owned companies as developer (Renewable UK, 2016); the gap in technological development and export capacity is far from being closed. The share of local content, or UK-based expenses (i.e. construction/capital, development, and operation & maintenance costs) is projected to remain relatively stable (BVGA, 2014), and has even decreased for larger projects, where capital expenditures far exceeds other costs (CEBR, 2012). Further, the Royal Academy of Engineering have called for a strengthening of the local (i.e. UK) supply chain (Royal Academy of Engineering 2014), which does not possess the ability to operate within other markets similarly to Danish, Spanish, and German companies, and it is currently dependent upon foreign direct investments (FDIs). This 'gap' between sources of technology and deployment of OSW is quite visible looking at the origin of the developer of offshore wind projects (Renewable UK, 2016): only 11 project (plus a demonstration plant) are UK-developed, with other 39 generated from foreign-based companies. Therefore, although the UK is a 'leader' in the deploying OSWs (Kern et al., 2014), this leadership appears driven by the availability of resource, which, even in the case of renewable energies, does not prevent the risk of 'Dutch disease' or resource curse (Brazilian et al. 2014; Månsson 2014), especially within a spatially unbalanced economy such the UK (Martin et al. 2015).

Using a strategy focused on attracting FDIs, while not supporting any specific national company, is not negative *per se*. However, the UK and its devolved governments are committed to utilize offshore (and, partly, on-shore) wind manufacturing for creating new, higher-paid manufacturing jobs, satisfying both domestic and foreign demand (Aitken 2010; OECD 2012; Okkonen and Lehtonen 2016). Further, FDIs can be affected by the uncertainty post-Brexit vote, preferring developing their presence in other waters across the North-Atlantic periphery (e.g. Iceland, Ireland, or Norway). Finally, energy-based economic development has the potential to drive wider, country-level development, as recent research has highlighted (Graziano et al., 2016); for a review see Carley et al., 2011) The question then is, then: what would the UK gain in increasing its local content in the OSW plants? Other countries within the EU have supported the creation of national firms (whether state-owned or not) within the OSW or the onshore wind sector. The following section presents the strategies adopted by three world-leading countries in exporting OSW technologies. Their strategies represent a way through which the UK could potentially attempt to foster the economic benefits from OSW manufacturing, although it is beyond the scope of the present work to ascertain what it would be the most effective and efficient one within the current policy framework.

2.1. Ways for governing local content and economic impact: the cases of Denmark, Spain and Germany

As of 2016, no UK company is in the list of the 10 most important wind manufacturers, neither for onshore or offshore power (Windpower Monthly, 2015; Technavio, 2015), and the UK is a net importer of wind technology. Within the EU context, three countries, Denmark, Germany, and Spain, have combined their low-carbon aspiration with the development of a domestic manufacturing wind industry.

The first of these countries, Denmark, historically is the European leader in wind technology (Jones and Boumane, 2011; IRENA, 2013a). Just like the UK, Denmark has a long wind energy tradition rooted in pre-industrial history. However, because of lack of coal and of access to oil fields, Denmark was able to maintain a constant political and social interest around wind energy (Jones and Boumane, 2011). In 1891, a Danish teacher from Askov, Poul la Cour, became the first person to carry out systematic experiments to use wind power to bring electricity to rural life. He also took care of educating the population on the possibility of wind energy, establishing a Society of Wind Electricians. By 1918, Denmark had built 250 electricity-producing wind turbines, 120 of which were connected to power stations: the only country in Europe with a wind turbines industry at the time. By 1945 Jacobs Wind, Lykkegaard Ltd. and F. L. Smidth & Co were possibly the largest wind power firms active in the global industry (Jones and Boumane, 2011).

This continuity in cultural and technical interest around wind power, along with the abundance of local resources, allowed Denmark to implement decisive long-term policies in the 1970s to produce wind. Because of its relatively small internal market, Danish firms looked towards foreign markets, establishing a path of export-oriented, manufacturing-focused culture within its entire wind sector (Frontier Economics, 2013), and supported by export-credit schemes (Lewis and Wiser, 2007). Full government support through R&D subsidies and incentives to develop local production guaranteed a continuous development that allowed Danish companies to be at the forefront of the wind technology market. Unlike the failed British attempt to export to, the Danish industry flourished in the US market, especially in California, allowing to turn relatively small companies into international corporations (Grubb, 1990b; Twidell and Brice, 1992; Jones and Boumane, 2011). In 1992, Denmark had 6778 turbines in California, against 112 from Britain (Jones and Boumane, 2011). In 1991, the introduction of a feed-in tariff system guaranteed Danish company the stability of price and therefore incentives to new investments that Britain lacked until 2013.

A second interesting comparison is with Germany, the European country with the largest installed wind capacity, 46 GW (IRENA, 2013b), which correspond to about 13% of total primary energy consumption (Phys.org, 2015). German renewable energy policies are indeed the most studied case of successful promotion of renewable technologies (Ćetković and Buzogány, 2016). The history of German energy is traditionally linked to coal and, from the 1960s, to nuclear power; until the end of the 1980s, these large utilities dominated the German system. However, the oil shocks in the 1970s and the 1986 Chernobyl incident brought about major changes in Germany's energy policies. Since 1979, the government has devised incentives to stimulate domestic market demand for renewables and from the mid-80s has constantly invested in R&D projects. In 1991 feed-in tariffs have also been introduced through clear and long-term policies, promoting the rapid penetration of wind power in the local energy bill. In 2000 a feed-in law guaranteed a fixed above-market price for electricity from renewables for a period of 20 years (Ćetković and Buzogány, 2016); since 2002 these measures have been extended to offshore technology. On the supply-side, the State has financed directly several important pilot projects, through a stable regulatory framework that facilitated access to loans and credits thanks to the government-owned development bank. Support schemes were also implemented on a municipal level, and there was an active participation towards energy transition on part of households, farmers and local companies. This decentralized and bottom-up participation largely made the expansion of the domestic market possible (Ćetković and Buzogány, 2016).

Building upon a solid manufacturing tradition, ambitious government investment programmes and focussed planning allowed Germany to develop a solid, state-of-the-art industry that easily penetrated in foreign market, especially in countries rich in wind but poor in technology such as the UK. Growing from the on-shore wind sector, German companies have been able to secure stable support from the government through the combination of stable feed-in-tariffs, R&D support (e.g. £67 million in 2011 alone for wind power, of which more than half for OSW), direct co-financing of OSW projects through the state-owned KfW Bankengruppe (IRENA, 2012; Frontier Economics, 2013; Mazzucato and Penna, 2015; Ćetković and Buzogány, 2016) including mandated export-oriented support (Cochran et al., 2014), quality control systems, and export-credit assistance similar to that in Denmark (Lewis and Wiser, 2007). Additionally, the larger resource availability off their coast have contributed to strengthen German domestic firms' operations, securing enough experience to compete on a global scale (Frontier Economics, 2013).

As a result, three German companies rank amongst the ten most important world's wind turbine suppliers, and German wind-turbine makers realize 70% of their profits abroad in 2011/2012 (Energy Digital, 2015; Lehr et al., 2012)

After Germany, the European country with the largest installed wind capacity is Spain, with 22,987 MW in 2014 (BP, 2013), roughly 19% of electricity demand (Red Eléctrica de España, 2016). The country started to develop its wind industry from 1986, with the first Renewable Energy Plan. Because of long-term feed-in tariffs, from the early 1990s utilities started to place large orders on wind farms; at the same time, well-designed policies for local manufacturing promoted both the investments in the country on part of foreign company and technology transfers for domestic companies. Differently to Germany and Denmark, Spain has also introduced mandatory local content requirements, in order for wind farms to qualify for national incentives (IRENA, 2013c). At the same time, the Spanish government created a national wind power manufacturing company, Gamesa. To balance the lack of experience necessary to manufacture wind farms, Spain encouraged the creation of a joint venture between Vestas, the largest Danish turbines manufacturer, and Gamesa (IRENA, 2013c), in order to be able to acquire the technology while respecting the local content requirements. Eventually, in 2001, Gamesa was able to buy Vestas' 40%, and it became to all effect a competitor of the Danish firm (IRENA, 2013c). Since 2007 the feed-in tariff system included offshore wind, with a rapid implementation of European directives.

It is important to notice that the retroactive revision of the renewable energy support legislation due to the financial crisis has strongly affected the domestic market, which is currently shrinking rather than expanding; a confirmation of the importance of policies that create a stable market environment in order to keep expanding the renewables market (IRENA, 2013c).

The comparison between the UK and the three most successful European energy wind industries shows that the main factors for the development of a strong wind industry are (Lewis and Wiser, 2007; IRENA, 2012; Cochran et al., 2014):

1. *a long-term, committed energy policy that incentives market expansion and the growth of domestic industries*
2. *the support of the local population and the creation of decentralised production networks*
3. *investments in R&D development that allows companies to become competitive in the international market*
4. *industry support, whether through mandates or through financing of the wind manufacturing sector as a whole, with clear industrial strategies.*

While the UK has a strong potential for the development of wind power, the delays in the development and the laissez-faire approach that has characterised its energy policy have brought to a delay in the creation of a strong local industry, which is now dependent on foreign imports (Ćetković and Buzogány, 2016). For example, a research conducted by the Department of Energy and Climate Change (DECC), a government body created in 2008 and recently abolished, shows that direct investments in renewable electricity generation is promoting the creation of a wide range of new jobs in existing as well as new established companies: 35,000 between 2010 and 2013 thanks to £31 million worth of private investments, and other 5,000 from £2.2 billion worth private investments made in 2013. Investments in research and development of local technology and an export-oriented policy based on investments will help to reach these goals. (DECC, 2013).

Table 1 (Irena 2013a; Irena 2013b; Irena 2013c; Irena 2013d; BP 2016)

	Strategy	**Installed capacity (2014)**	**% of wind in total electricity consumption (2015)**	**National companies**
DK	- Feed-in tariffs (1991) - constant R&D development (1970s onward) - export-oriented (US market)	4778 MW (BP data)	42%	- Vestas

	- social and political support			
DE	- feed-in tariffs (1991) - constant R&D development (1970s onward) - export-oriented - strong social and political support after 1986 Chernobyl	40500 MW (BP data)	12.9%	- Siemens - Enercon - Nordex - Senvion - E.on - Dong
ES	- feed-in tariff (1991) - Local Content Requirement on a local, not national level - promoted joint ventures with foreign companies (Vestas) - export-oriented policy from 2001 (Gamesa goes public) - social support	22987 (BP data)	18.9%	- Gamesa
UK	- NFFO, then ROCs, Feed-in-Tariff only from 2013 - CfDs - no development of local industry for onshore wind; creation of the Offshore Renewable Energy Catapult for offshore wind, research centre (2013) - until recently no social support	12808 (PB data)	11%	N/A

3. Methods and simulation strategy

3.1 The modelling framework

In this section, we briefly describe the modelling framework used in this exercise and the simulation strategy adopted to evaluate the macroeconomic effects of an expansion in the offshore wind sector. We use an existing computable general equilibrium model, the UKENVI model, initially developed by Allan et al., (2007) and subsequently updated with new model features in Lecca et al., (2014) and Lecca et al., (2016). We adopt the latest version of the model whose features are fully described in Lecca et al., (2016).

UKENVI is a large numerical modelling framework that allows for great flexibility. Within periods the production and consumption structures are characterized by hierarchical Constant Elasticity of Substitution functions with Leontief and Cobb-Douglas as special cases. Between periods, consumers and investors can choose to alternatively adopt myopic or forward looking expectations. The type of wage setting installed in the model implies that the real wage is inversely related to the unemployment rate as in Blanchflower and Oswald (1994).

There are two external sectors in the model with which the UK trades: Rest of European Union (REU) and Rest of World (ROW) where an Armington (1969) link determines the amount of imports and exports to and from the UK. Under this assumption, domestic and imported goods are imperfect substitutes and respond to changes in relative prices.

The household income consists of the labour income, the capital revenue and government transfers. A fixed share of the disposable income is allocated to savings, whereas the remaining part is allocated to the consumption of final goods and services. Government expenditure includes current spending on goods and services and transfers to households and firms. Its revenues are given by labour and capital income taxes, indirect taxes on production. When a balanced budget is applied either government consumption or the income tax rate are endogenous. In this specific case we assume fixed government consumption and no change in taxes.

The investment decisions are separated from the decision of investments allowing for unconstrained balance of payment. Furthermore, equilibrium in the commodity markets is sufficient to guarantee equilibrium also in the payments account since we are not considering money as a commodity. As for the capital market, capital demand equals the capital stock and the labour market is equilibrated through endogenous changes unemployment rates.

The model calibration implies using the data derived from the UK Social Accounting Matrix for the year 2010 disaggregated into 25 industries of which 13 are energy sectors. Among energy sectors the model distinguishes between electricity transmission and electricity generations. The latter is disaggregated into 8 types of electricity generation: Generation – Coal, Generation -Gas + Oil, Generation – Nuclear, Generation – Hydro, Generation – Biomass, Generation – Onshore Wind, Generation - Wind Offshore, Generation - Marine/solar and Generation – Other. A full description of the data and calibration can be found in Lecca et al., (2014) and Lecca et al., (2016).

3.2 Constructing the scenarios

We now turn to describe how the capital and operational costs have been estimated. Our estimates are based on the DECC's capacity projection. The annual installed capacity and the corresponding cumulative capacity expressed in GW are reported in Figure 1. According to DECC's (2011 and 2013) projection the deployment potential of offshore wind power would be around 52 GW by 2030 in the more optimistic scenario[2]. The leased capacity in the UK can be decomposed in 1.5 GW, Round 1, 9.2 GW, Round 2 (including Round 2 extension), 32.2, Round 3, and 10 GW in the Scottish Territorial water zones.

Using the generation costs estimated by DECC 2011, we have constructed the capital (CAPEX) and operational (OPEX) expenditures, estimated for the period 2010-2030. Since the costs per £/KW of CAPEX and OPEX associated to each Round is different, we calculate for each type of expenditure a weighted average cost reflecting the capacity leased in each Round. Given that not all capital goods and services are purchased locally, in our base case scenario, we assume an average local content over the period 2010-2030 of 19% and 76% (BVGA, 2014) for CAPEX and OPEX respectively.

The resulting average expenditures calculated over the period 2010-2030 divided by category of expenditures are reported in Figure 2. We observe that while expenditures on offshore wind devices fall within a number of different categories, roughly 30% of total expenditures are costs related to the nacelle and hub. The other important components are Development and project management, Foundation and Substation installation. We then use a bridge matrix (see ORE Catapult, 2014) to convert category of expenditures into economic sectors.

[2] DECC also provides medium and low projections. However, in our experiment we choose the more optimistic case. Given the purpose of this paper the analysis of the other two scenarios does not create added value to the paper. Indeed, the results can be easily rescaled downwards.

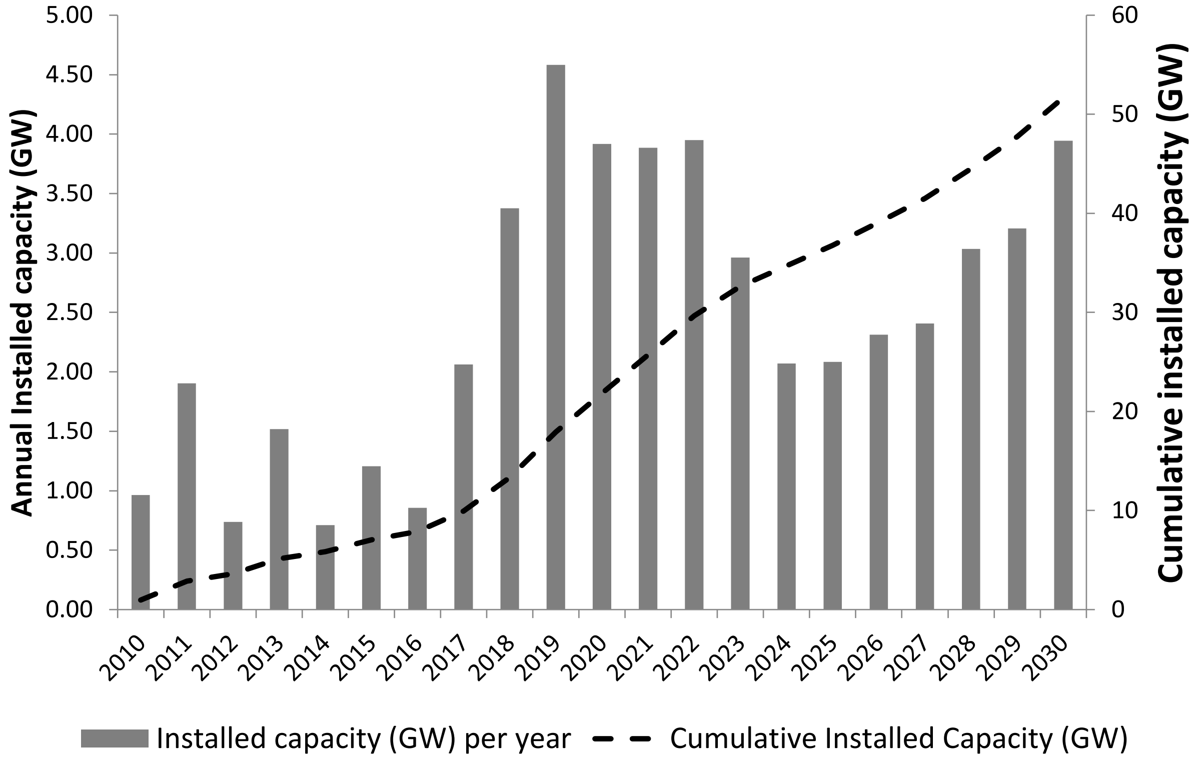

Figure 1 Offshore Wind capacity projections in the UK (source: DECC, 2011 and 2013)

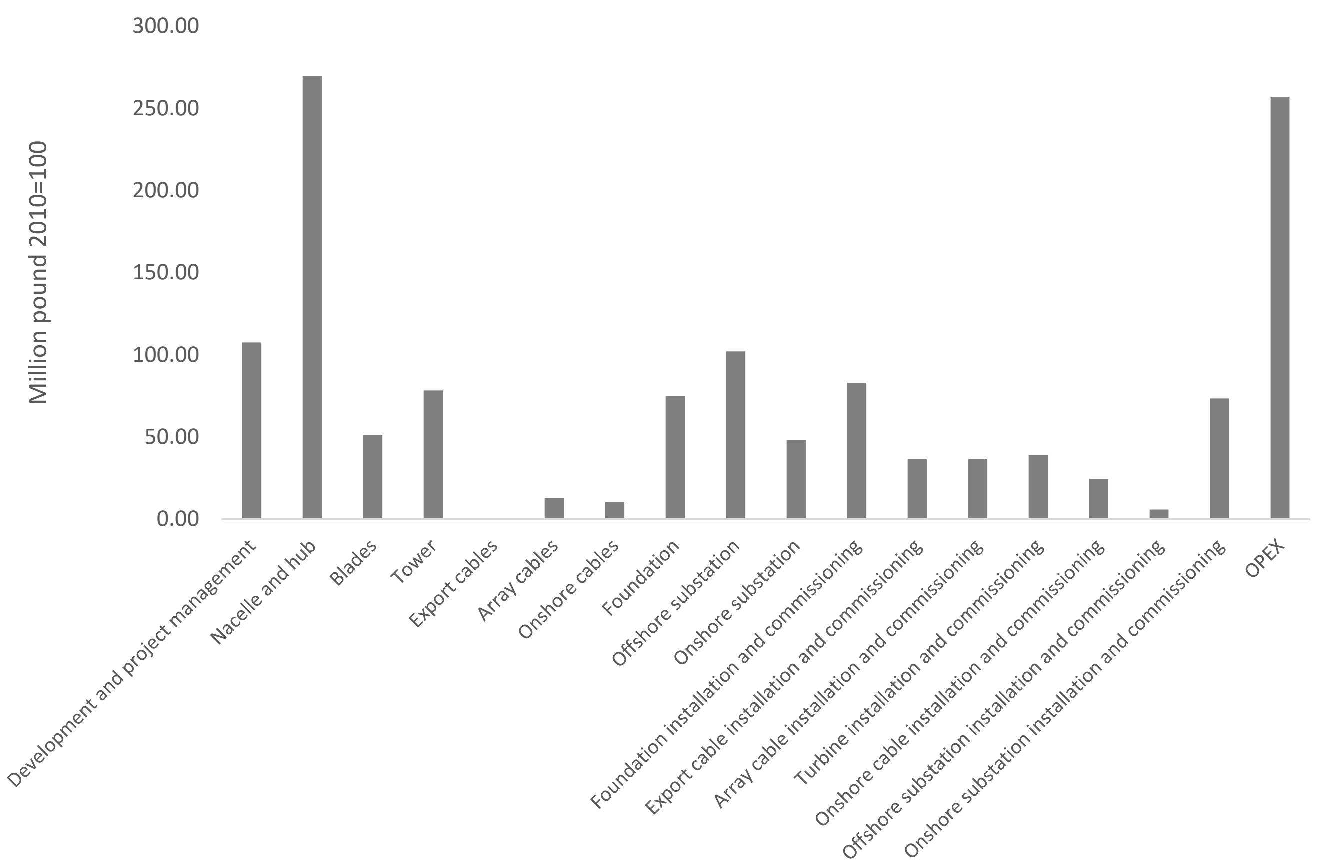

Figure 2 Costs by category of expenditures, annual average 2010-2030

4. Results of the simulation

The operational costs are entered in the model as an increase in the final demand, without directly influencing the supply-side of the economy. Therefore, the increase in output, GDP and employment are primarily driven by a conventional Keynesian multiplier effect adjusted by change in prices through increased wages. The augmented final demand generates a rise in labour demand thereby reducing unemployment and therefore increasing the real wage. Typically for a demand shock, we would expect an increase in prices and a fall in competitiveness since the supply-side of the economy is only indirectly affected through induced effects on output.

For the case of capital expenditures, the shock is implemented via subsidies to investments. The subsidy directly impacts the user cost of capital putting downward pressure to all the other prices in the economy. A fall in the cost of capital services increase substitution towards capital inputs and the improved profit expectation drives additional investment that in turn further enhances the increase in growth and competitiveness.

The simulation performed is therefore a combined demand- and supply-side shock. While both shocks, in the absence of explicit crowding out effects, are able to generate an increase in economic activity, the mechanisms and the transmission channel associated to them differ dramatically.

4.1 Analysis

The overall impact of the combined shock is reported in Figure 3. In this Figure, we plot the percentage deviations in GDP and employment, from base year values from the beginning of the shock until full adjustment is achieved. Both variables follow a similar pattern during the all transition path, shifting up and down reflecting mainly the uneven allocation of investments across periods.

Figure 3 The impact on GDP and employment

The pick is reached in 2024 where the GDP and employment increase by 0.43% and 0.3%, respectively from base year values. The shock terminates in 2030, hereafter the economy does not receive any additional injection however, GDP and employment are still above their base year values for the entire transition path. The positive legacy effects we observe are therefore the result of the pre-accumulated capital stock. Soon after the end of the shock, firms would start to disinvest and the corresponding legacy effects will continue to generate positive effects until full depletion of the additional stock generated by the project.

We notice that the changes in GDP are higher than the change in employment, meaning that the capital stock is increasing more than labour in all periods. The reason for it can be found in the increased firm's preference toward capital services: as investments increase through subsidies, downward pressure on the user cost of capital is observed, creating bigger substitution effects away from labour. Thus the behaviour of prices determined the substitution effects between capital and labour.

As we show in Figure 4, the cost of capital falls while wages are increasing generating in turn preferences for capital services. In this Figure we also plot the evolution of the consumer price index, which is above the base year value for the first 15 periods, subsequently falls below the base values, until eventually adjusting back to base year levels.

Furthermore, we observe that the percentage changes from base value in the consumer price index are always below the nominal wages, meaning that real wage is rising, producing an increase in household income and therefore an increase in household consumption boosting the economy even further.

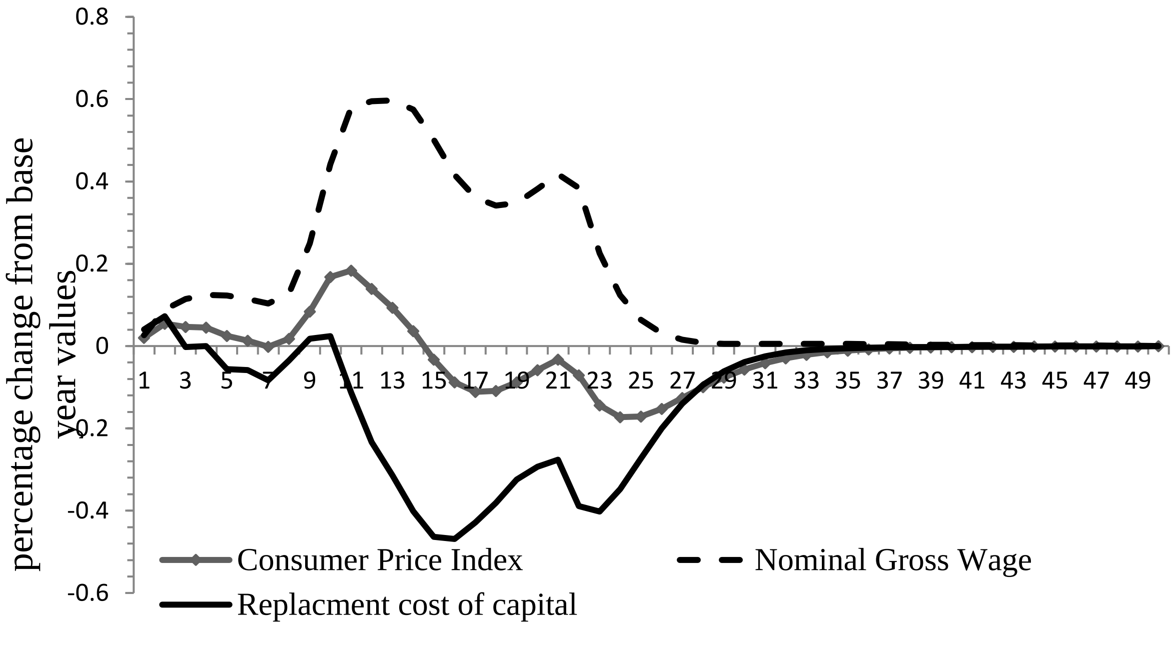

Figure 4 The behaviour of selected prices

4.2 The impact of changing the local content of capital expenditures

The determinant of the UK growth associated to the expansion of the offshore wind sector is strictly dependent from the amount of capital goods and services supplied by the domestic economy. The assumptions adopted until now are based on the current situation, that is to say projections of the local supply are generally determined by computing to what extent the local supply chain has the capacity to meet the expected increase in demand. Currently, in the UK there is a significant supply chain activity in the offshore wind sector, however this is not enough to meet the expected increase in demand specifically driven by the UK incentive to the sector and furthermore local companies are not as much competitive as their overseas counterparts on some specific manufacturing such as turbines and/or foundation which typically represent a significant share of the overall investment (see for instance, The Crown Estate, 2014).

The UK government through the MAS Offshore Wind Supply Chain Growth Programme (ref.) has implemented an industrial strategy where the main objective is to support the competitiveness and process improvement of local companies to allow the domestic supply chain to be able to meet the upcoming demand especially in consideration of the UK's budget 2016 that ensures new “contracts for difference” (CfD) funding of around £700 million to support offshore wind projects, although no local requirements are introduced at national nor at devolved level.

In our experiment we therefore assess what would be the likely economic impact of expanding the offshore wind sector if the UK content related to the capital costs increases progressively to reach that currently estimated for the onshore wind sector. Although currently costlier and partly embedded in different policy landscapes (Söderlhom and Pettersson, 2011), off shore wind power shares several technological characteristics with onshore wind, including the profile of players operating within these two sectors (Nemet, 2012; Gernaat et al., 2014).

The difference between the base-line scenario, and this increased scenario based on the experience of onshore wind (roughly 68% of locally supplied expenditures, Renewable UK, 2012) quantifies the localization ‘prize’ in terms of additional benefits to the UK economy should the government implement any of the strategies followed in past years by other major countries such as Germany, Denmark or Spain. In Figure 5, we plot the UK local content assumed for our default scenario (dash line) and the locally supplied capital goods that could be achieved under the hypothesis of further development of the local supply chain (solid line). The assumption is that the local supply of capital good will increase by 4% per year from 2020 until the onshore wind local content is reached in 2030. This implies 68% of goods and services purchased within the domestic economy, a share similar to the one of OWP in 2014 (Renewable UK, 2015). The differences in the macroeconomic impact are reported in Figure 6, where the cumulative GDP impacts under the two import assumptions are plotted. It can clearly be observed that the macroeconomic benefits of further improvement in the local supply chain are of high importance if the development of offshore wind sectors does not only have the objective of generating environmental benefits but has also the aim to boost the economy.

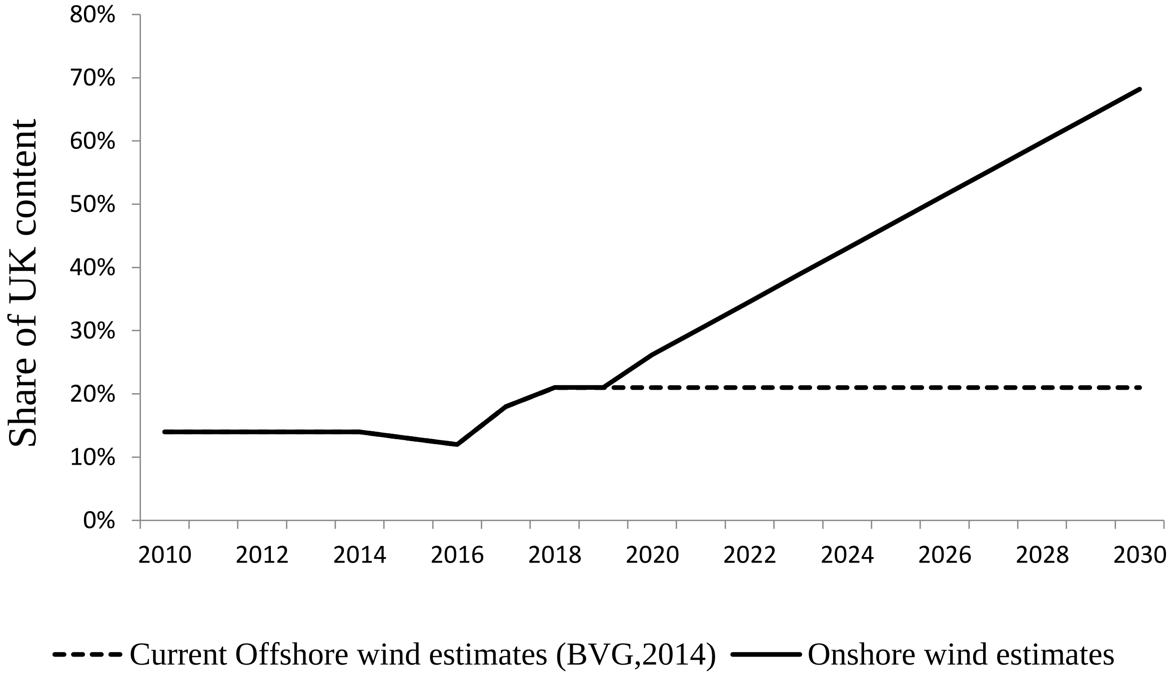

Figure 5 Local content under two alternative assumptions

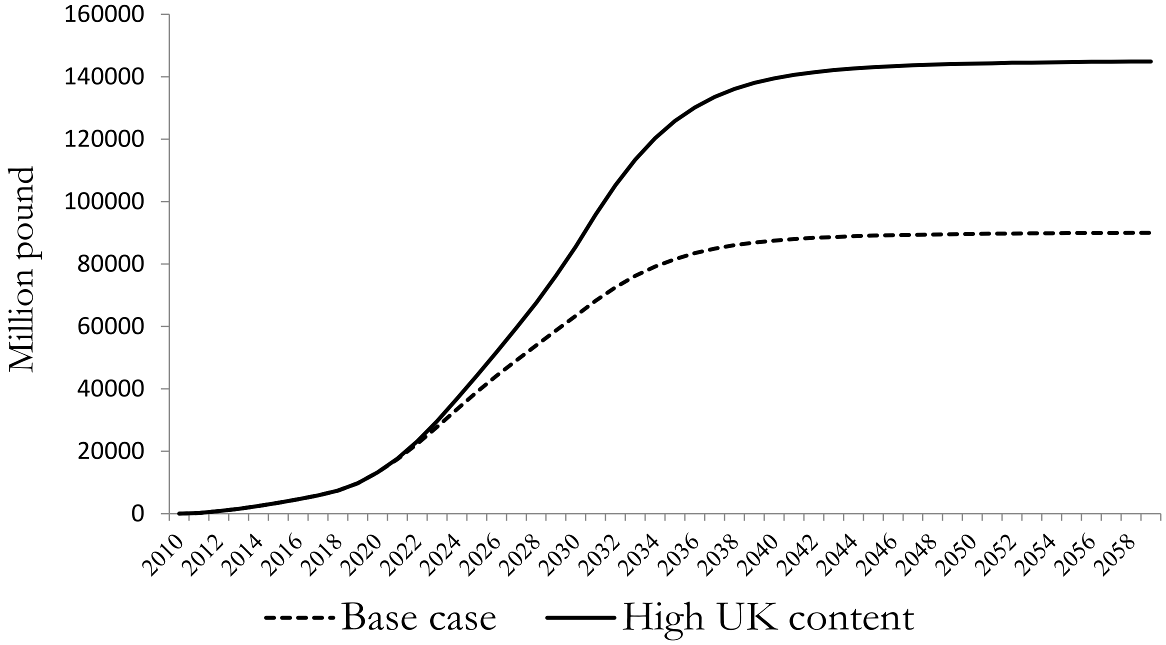

Figure 6 GDP cumulative deviations from base year values (£MM) under two different assumptions about UK content

Our simulation experiment suggests that moving to higher local content, from 22 to 68%, a level similar to that of onshore wind, could generate a larger income effect in the economy. The cumulative income effect is roughly 60% higher than the default case according to our simulation results.

4.3 Does agents' expectation matter?

In our exercise, we have simulated the temporary shock associated to the expansion in the offshore wind sector. The dynamic framework used implies that economic agents take decisions based on the past, abstracting for future events. It is interesting however to consider also the case in which consumers and investors take current decisions on the basis of expected income and profitability. In consideration of the subsidies currently available for the offshore wind sector, the path of continuous changes in the structure and objectives of renewable energy support schemes in the UK, and the high uncertainty around the future of renewables, the impact associated to the expansion in the OSW can be dramatically lower. Therefore, in Figure 7 we show the cumulative GDP deviation from base year values obtained under two alternatives agent's expectation specifications. The solid line represents the cumulative GDP deviation under myopic expectations (already plotted in Figure 5) which is our default case. The dash line represents the cumulative GDP deviation from base year values as results of agents making forward looking choices.

Under the myopic assumptions, economic agents believe that policy support to offshore wind will be permanent, while under the perfect foresight model the agents know exactly will eventually ends. As we can see from Figure 7, the resulting macroeconomic impact over the longer run is significantly lower under forward looking agents. Indeed, since the beginning of the shock, investors, in particular, are aware that the incentives implemented through subsidies is not persistent and will end after 20 periods. This is therefore preventing investors to make additional investments and inhibiting household to benefit from the additional income. Furthermore, under the forward looking case, investors immediately after the exogenous shock will start disinvesting nullifying the positive legacy effects we encountered under the myopic case.

The differences emphasized between the two types of agent's behaviour are of extreme importance for the UK at the moment and have implications for the policy credibility. Subsidies through the contract for differences scheme are remarkably important to support investment in the offshore wind sector in particular and new low carbon generations in general. If for example investors face uncertainty over the timing of implementation of subsidies or perceive that the support to the offshore wind sector luck of credibility the economic impact will be significantly lower.

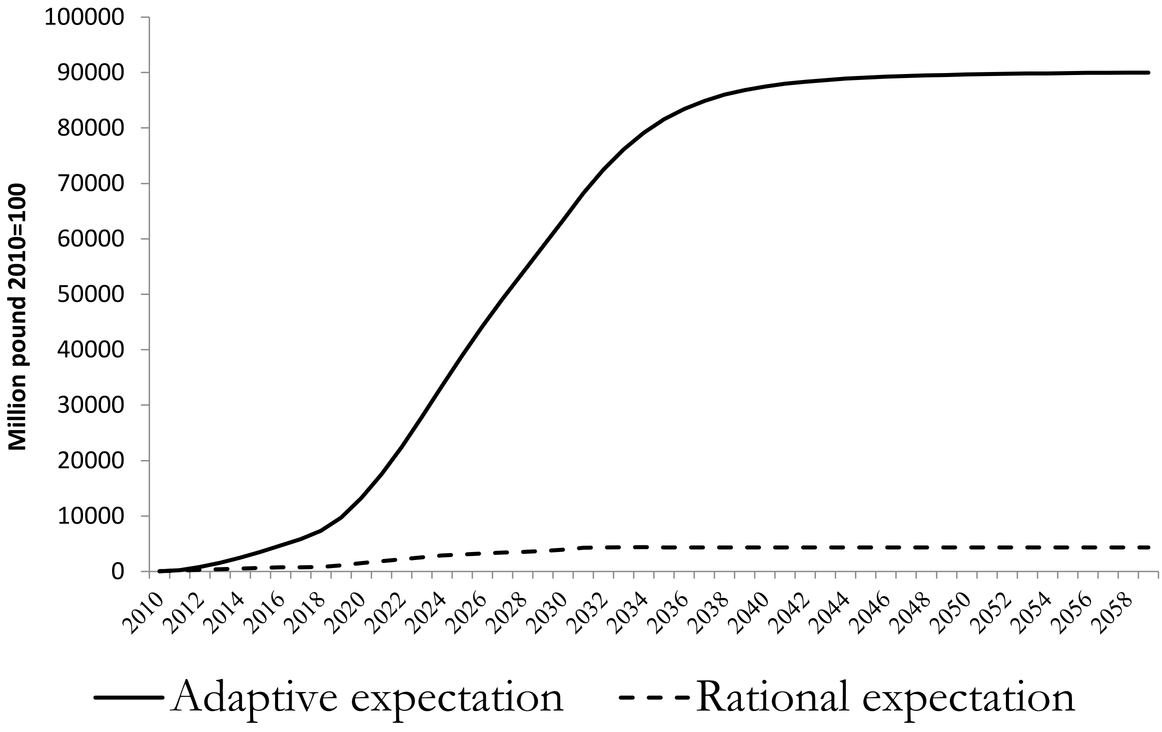

Figure 7 Cumulative GDP under myopic and forward looking agents

5. Conclusions and Policy Implications

Supporting policies targeted to the expansion of electricity generation from renewable energy in general and OSW in particular have the ambition to improve environmental quality. In this paper, we do not question the capacity to achieve this important objective. Instead, we attempt to show that policies aimed at supporting these technologies, and whose expectation is to generate widespread and positive macroeconomic impacts, might fail to achieve this objective under certain circumstances. Specifically, we consider to important factors influencing these macroeconomic outcomes: *i) the extent to which the local supply chain is developed enough to satisfy the additional increase in demand of OSW; and ii) the response of economic agents under the uncertainty associated to governmental support.* Both these factors are influenced by past policies, which can be designed to directly influence the renewable energy sector (e.g. CfDs), or whose effects are powerful enough to establish a multi-sectoral influence (e.g. in the case of export-oriented policies in Germany). Furthermore, the overall ability of governments to reduce the uncertainty linked to the support policies is necessary to guarantee significant and continuous macroeconomic impacts. Past experiences can influence agents' decisions, and history shows that uncertainty, rather than by stable support, is a major actor in undermining investments in renewables (Lewis and Wiser, 2007; IRENA, 2013; Ćetković and Buzogány, 2016)

Our modelling exercise suggests that the magnitude of the impact significantly increase with improvement in the local content. The reduction of capital goods imported from outside the country and the resulting increase in offshore related technologies supplied locally generate larger increases in GDP and consequently more jobs are created in the country. In the model, we assumed that local content would rise up to levels similar to those of a related and more mature sector, OWP.

Additionally, we have found policy uncertainty to jeopardize any potential expansion of the local supply chain. Essentially our results suggest that the behaviour of economic agents in relation to the uncertainty associated to the subsidy could be even more important than further development of a competitive supply chain in the country. We have tried to mimic such a behaviour assuming forward looking agents in a context of temporary government support to offshore wind in contrast to myopic agents. In the first case, agents know in advanced that the subsidy cease after some point in time, therefore they start to disinvest before the policy support will terminate. On the contrary myopic agents abstract from the futures, meaning that investors make their decision to invest assuming that they receive the subsidy every year. Two lessons can be learned by our analysis. Firstly, the 'prize' for increasing local content can be substantial, although, in the context of the UK, an historic lack of direct or indirect intervention, and especially a lack of policies to support export-oriented advanced manufacturing, suggest these 'local content premium' might not be attained in the short term, even after the Brexit vote, due to a lack of actor-firms capable of seizing this opportunity. Secondly, the historic uncertainty of renewable energy support policies in the UK has a high cost in terms of reduced macroeconomic benefits. In this sense, linking the implementation of renewable energy to more than one policy domain (emission reduction + economic development) has the potential to stabilize the policy landscape, thus generating confidence in the investors (Carley et al., 2011; Graziano et al., 2016).

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